

Ecole d'été BDA MDD 2024

How to conduct scientific experiments to enhance your research outputs

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https://schools.dvrc.fr/MDD24/workshops/How_To_XP.pdf

Research and Experiments

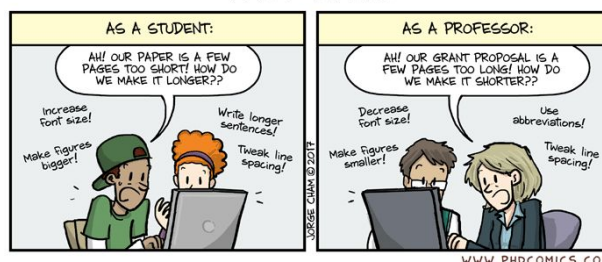
How to perform research?

Get "empirical" results

How to write research?

Get papers accepted

PAGE LIMITS



Sources and Thanks

“Research and Methods in Computer Science”

S. Demeyer, University of Antwerp, 2018

“Case Study Research: Design and Methods”

R. K. Yin., 3rd Edition. SAGE Publications. California, 2009.

“Guidelines for Conducting and Reporting Case Study Research in Software Engineering”

P. Runeson, M. Höst. Empirical Softw. Eng. 14(2), 2009, 131-164.

“Steps in Conducting a Research Project or Experiment”

H. Zaleski, Experimental Design and Data Analysis Workshop, 2003.

<http://PhDcomics.com>

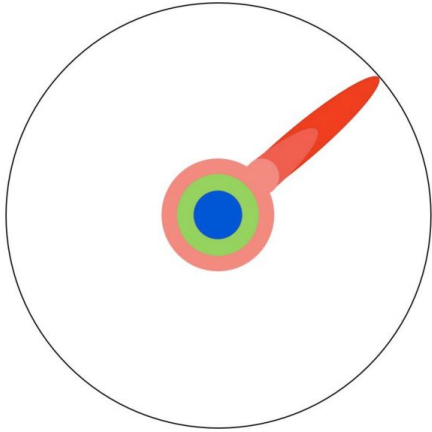
1 Introduction
Research?

2 Conducting Experiments: Case Studies

3 Case studies

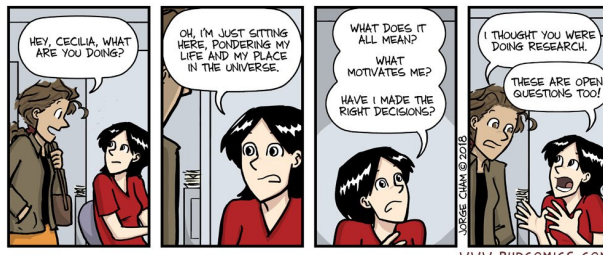
4 Practice Works

What is Research?



- Human knowledge
- Elementary School
- High School
- Bachelor
- Master
- Ph.D (~first year)
- Ph.D (~defense)

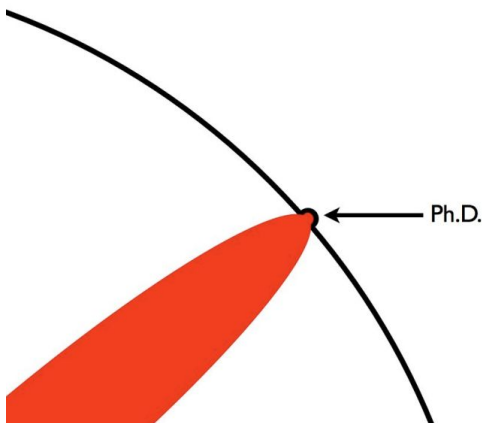
<http://gizmodo.com/5613794/what-is-exactly-a-doctorate>



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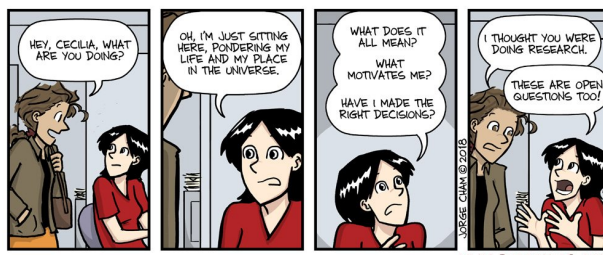
How To XP?

What is Research?



- Human knowledge
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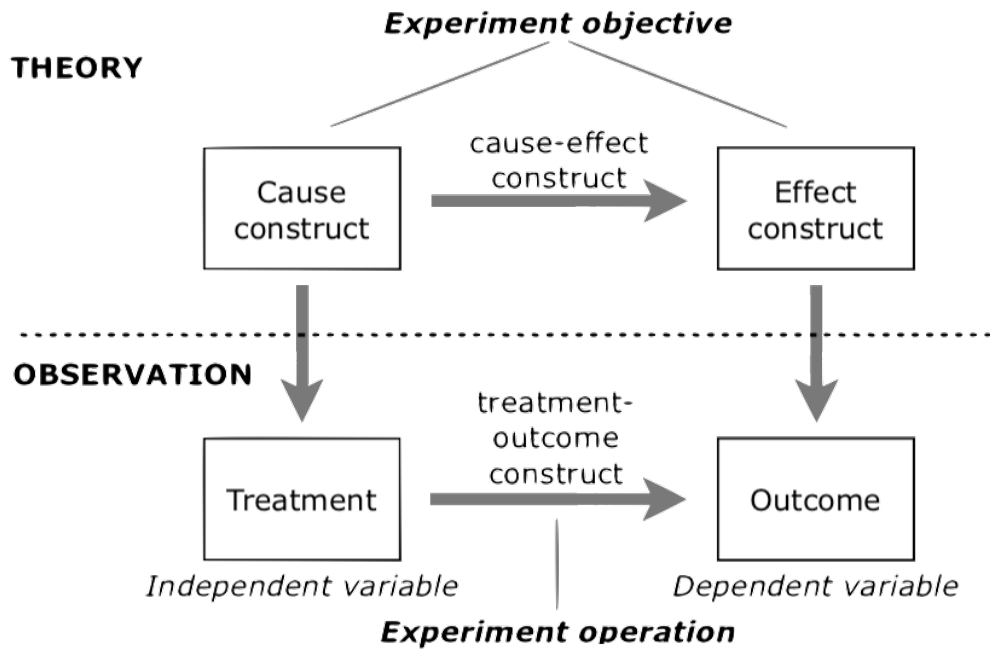
<http://gizmodo.com/5613794/what-is-exactly-a-doctorate>



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How To XP?

Experiments Principle



C. Wohlin, et al. "Experimentation in Software Engineering - An Introduction", Kluwer Academic Publishers, 2000
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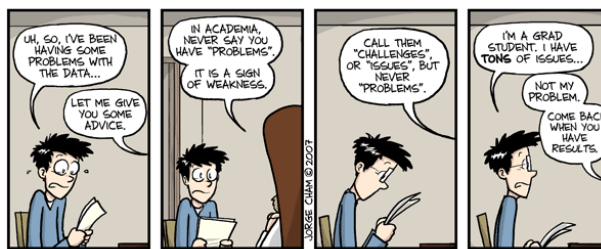
Case studies

Widely used in Computer Science

⚠ "studying a case" vs "doing a case study" ⚠

Case studies typology:

- | | |
|-------------------------|-------------------------------|
| Feasibility study | <i>Is it possible?</i> |
| Pilot case/Demonstrator | <i>Is it appropriate?</i> |
| Comparative study | <i>Is it better?</i> |
| Observational study | <i>What is it?</i> |
| Literature survey | <i>What is known/unknown?</i> |
| Formal model | <i>Underlying concepts?</i> |
| Simulation | <i>What if?</i> |



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Feasibility Study

Here is a new idea, is it possible?

Ex: “CAP Theorem”

Is it possible to solve a specific kind of problem... effectively?

Computer science perspective ($P = NP$, Turing test, etc.)

Engineering perspective (build efficiently; fast & small)

Economic perspective (cost effective & profitable)

Is the technique new / novel / innovative?

Compare vs alternatives (*literature survey; comparative study*)

Proof by construction

Build a prototype

Often by applying on a “CASE”

Conclusions

Primarily qualitative: “lessons learned”

Quantitative: economic, engineering

Feasibility Study: Example

Three main properties manage database:

Consistency

Availability

Partition tolerance

CAP Theorem: Any database CAN ONLY HOLD two of the properties

Proved by construction¹.

¹Eric A. Brewer, "*Towards robust distributed systems*", PODC, p.7, 2000

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2 Conducting Experiments: Case Studies

Feasibility Study

Pilot Case

Comparative Study

Observational Study

Literature Survey

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Pilot Case/Demonstrator

Here is an idea that has proven valuable; does it work for us?

Ex: Apply consistency on Cassandra or MongoDB

Proven valuable

Accepted merits (e.g. “lessons learned” from *feasibility study*)

Some implicit theory explains why the idea has merit

Does it work for us?

Context is very important

Demonstrated on a simple yet representative “CASE”

“Pilot Case” ≠ “Pilot Study”

Proof by construction + prototyping + applied on a “case”

Conclusions

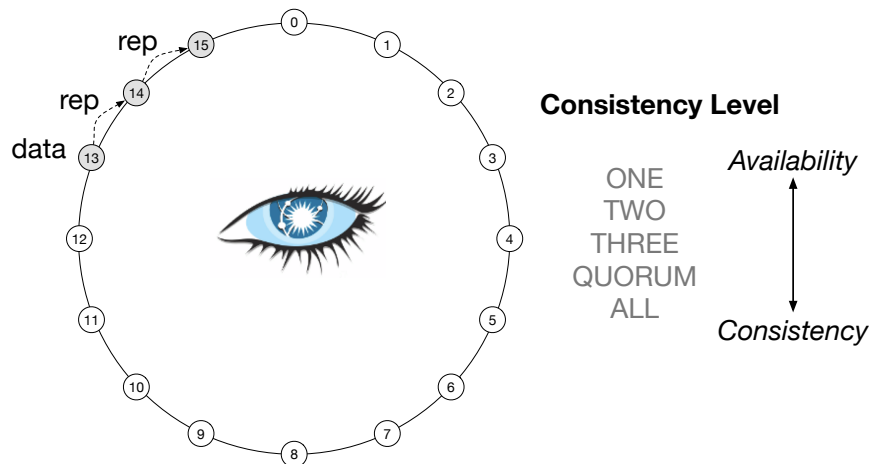
Primarily qualitative; “lessons learned”

Quantitative; preferably with predefined criteria

⇒ compare to context before applying the idea

Pilot Case/Demonstrator: Example

How can we handle both AVAILABILITY and CONSISTENCY on the distributed database *Cassandra*?



Conclusion: CAP Theorem → PACELC Theorem²

²D. Abadi, “Consistency Tradeoffs in Modern Distributed Database System Design: CAP is Only Part of the Story”, *Computer Journal* 45(2), 2012, pp. 37–42

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Comparative Study

Here are four/five techniques, which one is better?

Ex: How denormalizing data models impacts NoSQL databases on a case?

For a given purpose!

Not necessarily absolute ranking

Where are the differences? What are the tradeoffs?

Criteria check-list

Should not favor one technique

Qualitative (remain **unbiased!**) and

Quantitative (what do you want to know?)

Criteria check-list should be complete and reusable!

If done well → most important contribution (*replication!*)

See literature survey

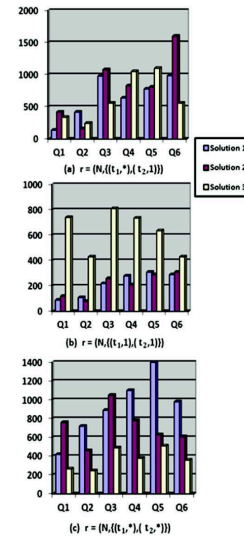
Compare

Score criteria check-list (apply on a “CASE”)

Comparative Study: Example

Benchmarking³ NoSQL databases: Cassandra & MongoDB

NoSQL system	Relationship	Solution	Query	Time (s)
Cassandra	$r = (N, \{(t_1, *), (t_2, 1)\})$	Solution 1	Q1	140
		...	Q4	980
	
		Solution 2	Q1	830
	
		Solution 3	Q4	420
	$r = (N, \{(t_1, 1), (t_2, 1)\})$	Solution 1	...	...
		...	Q5	310
		Solution 2	...	...
		...	Q6	290
		Solution 3	...	...
		...	Q4	735
MongoDB	$r = (N, \{(t_1, *), (t_2, *)\})$	Solution 1	...	...
		...	Q2	720
		...	Q5	1400
	
		Solution 2	Q3	1050
	
		Solution 3	Q5	510
		...	Q6	530
		Solution 1	...	...
		...	Q4	4300
Solution 2	...	...
...	Q6	6200		
Solution 3	...	...
...	Q5	1700		
Solution 4	...	...
...	Q6	1500		
...	Q2	870		



Performance of data models wrt. NoSQL solutions

³F. Abdelhedi et al., "MDA-Based Approach for NoSQL Databases Modelling", Big Data Analytics and Knowledge Discovery, 2017

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Observational Study

Understand phenomena through observations

Ex: Tourists' behavior on Tripadvisor

Systematic collection of data derived from direct observation of the everyday life
Phenomena is best understood in the fullest possible context

Observation & participation
Interviews & questionnaires

Observing a series of cases "CASE"

Conclusions

Primarily qualitative:
classifications/observations/...



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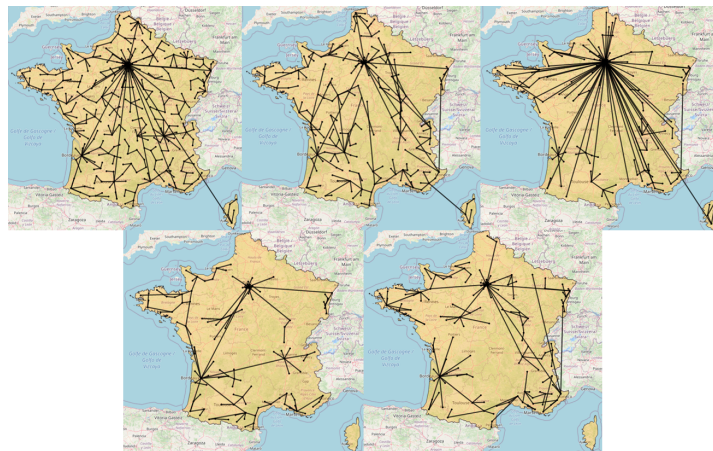


Observational Study: Example

Graph data model on Tourists' circulation: Propagation analysis

Graph data model, aggregation operations, graph algorithms

Graph topology & geodesic measure⁴



Propagation over France of: French, British, Americans, Spanish, Italians

⁴H. PrevotEAU et al., "Propagation Measure on Circulation Graphs for Tourism Behavior Analysis", Software Applied Computing, 2022

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Literature Survey

What is known? What questions are still open?

Ex: How do recommendations systems work?

Comprehensive: **Precise research question**⁵

Define:

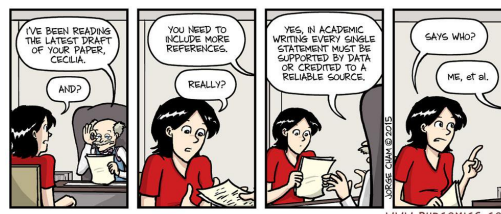
- A search strategy: rigor, completeness, replication
- A scope: criteria for inclusion and exclusion

Specify information to be obtained

The "CASES" = selected papers

Organize conclusions:

classification	taxonomy	conceptual model
table	tree	frequency



⁵B. A. Kitchenham, "Procedures for Performing Systematic Reviews", Keele University Technical Report EBSE-2007-01, 2007

Literature Survey: Example

Survey on self-tuning database systems⁶:

((schema design OR physical design OR schema configuration OR schema self-tuning OR index OR materialized view OR partitioning OR clustering) AND (autonomic database OR relational database OR data warehouse OR OLAP))
 OR
 ((modeling OR schema OR design OR tuning OR Model) AND (key-value OR document OR column OR graph) AND (NoSQL OR database OR data warehouse OR OLAP))

Database Type	Publication Type	Primary Studies	Years of Pub
SQL Databases	Journal	40	1974–2021
	Conference	64	1976–2021
	Book	3	1983–2020
	Dissertation or technical report	7	1970–2020
	Total	114	1970–2021
NoSQL Databases	Journal	21	2014–2021
	Conference	49	2010–2021
	Book	1	2019
	Dissertation or technical report	1	2018
	Total	72	2010–2021

Survey Methodology

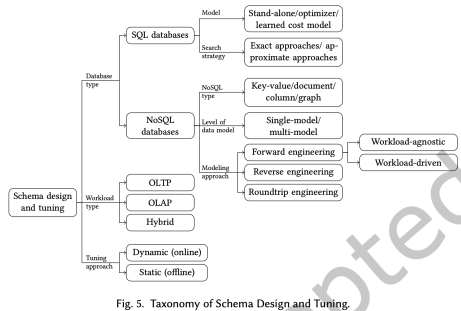


Fig. 5. Taxonomy of Schema Design and Tuning.

Taxonomy of Technics

Papers Analysis

Study	NoSQL Type	Level of Data Model	Workload	Modeling Approach			Tuning Approach	
				Forward	Reverse	Roundtrip	Static	Dynamic
[1]	Column, Document, Graph	Multi-model	OLTP	✓				✓
[15]	Column, Document, Graph	Single-model	OLTP	✓				✓
[65]	Document, Graph	Multi-model (Multistore)	OLTP	✓				✓
[125]	Document, Graph	Single-model	OLTP	✓				✓
[140], [144], [177]	Column	Single-model	OLTP	✓				✓
[104]	Document	Single-model	OLTP	✓				✓
[66], [5], [11]	Graph	Single-model	OLTP	✓				✓
[72], [53], [51], [199]	Column	Single-model	OLAP	✓				✓
[250], [53]	Column, Document	Single-model	OLAP	✓				✓
[52], [54]	Document	Single-model	OLAP	✓				✓
[209], [10]	Graph	Single-model	OLAP	✓				✓
[75]	key-value	Single-model	OLAP	✓				✓
[218], [29], [144], [50], [79]	Column	Single-model	OLTP	✓				✓
[71], [117], [173], [114]	Document	Single-model	OLTP	✓				✓
[18], [19]	key-value, Column, Document	Multi-model	OLTP	✓				✓
[158]	key-value, Column, Document, Graph	Multi-model	OLTP	✓				✓
[167]	Column	Single-model	OLTP	✓				✓
[89]	key-value, Column, Document, Graph	Multi-model (Polystore)	OLTP	✓				✓

Review of Approaches

⁶ Maryam Mozaffari, Anton Dignös, Johann Gamper, and Uta Störl. "Self-tuning Database Systems: A Systematic Literature Review of Automatic Database Schema Design and Tuning" (May 2024)

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Formal Model

How can we understand/explain the world?

ex: How to find the best denormalized data models?

Make a mathematical abstraction of a certain problem

Model: Analytical, stochastic, logical, etc.

Often explained using a "CASE"

Prove some important characteristics

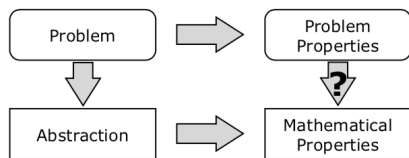
Based on inductive reasoning, axioms & lemma's...

Motivate

Irrelevant vs relevant factors

Which properties are worthwhile (proven)?

→ See literature survey

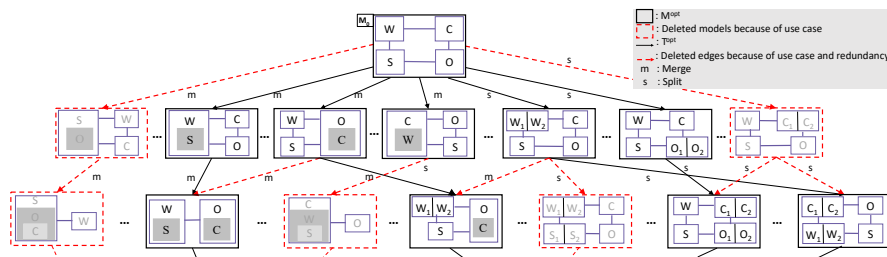


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Formal Model: Example

Formal model of data models denormalization⁷:



Theoretical graph of denormalized solutions

Formal definition of data models' transformation rules;

Proof of completeness;

$$\text{Complexity of the problem: } |\mathcal{M}^*| = Fn_{|\mathcal{L}|} \times \prod_{k=1}^{|\mathcal{R}|} B_{|keys(r_k)|};$$

$$\text{Reduction of the complexity: } |\mathcal{M}^{opt}| = Fn_{|refs(Q)|} \times \prod_{k=1}^{|\mathcal{R}|} |KeySet(Q_k)|.$$

⁷Mali et al., "A Global Model-Driven Denormalization Approach for Schema Migration". Research Challenges in Information Science, 2022, pp 529–545

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Simulation

What would happen if ... ?

Ex: How to simulate the behavior of data models denormalization?

Study circumstances of phenomena in detail

Real world too expensive; too slow or impossible

Make prognoses about what can happen in certain situations

Test using real observations, typically obtained via a “CASE”

Heisenberg uncertainty principle⁸

Motivate

Which circumstances are irrelevant (excluded) and which are not (included)?

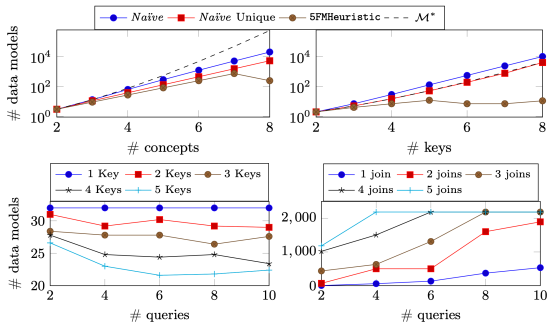
Which properties are worthwhile (to be observed/predicted) ?

→ See literature survey

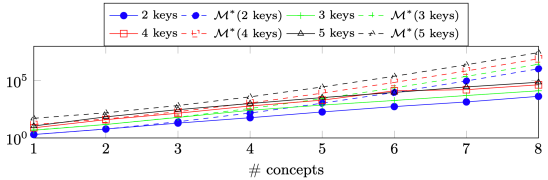
⁸Hazewinkel, Michiel, ed. (2001), “**Uncertainty principle**”, Encyclopedia of Mathematics, Springer Science+Business Media B.V. / Kluwer

Simulation: Example

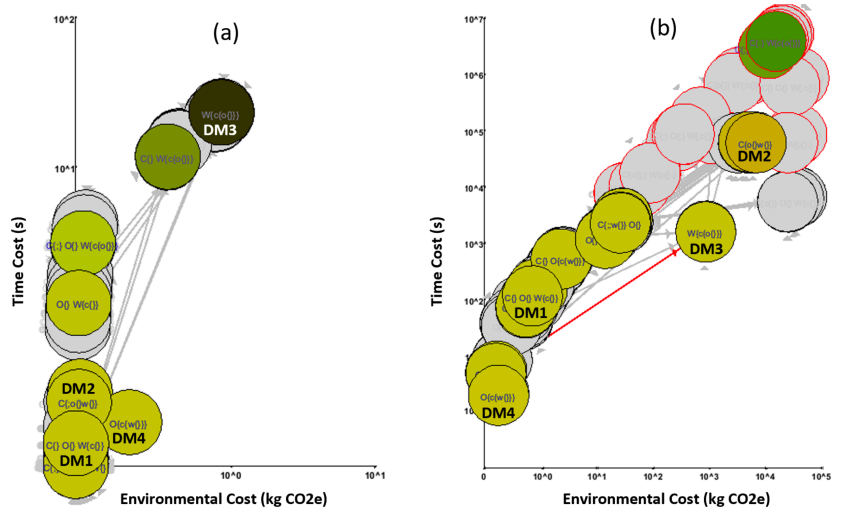
Simulation of the impact of denormalization on use cases⁹:



Denormalization impact on queries



Complete use case's impact



Simulation of denormalization impact of environment vs time

⁹ Jihane Mali, Faten Atigui, Ahmed Azough, Nicolas Travers, Shohreh Ahvar. "How to Optimize the Environmental Impact of Transformed NoSQL Schemas through a Multidimensional Cost Model?" CoRR abs/2311.15406 (2023)

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 - Revisit
 - Definition
 - Performing Experiments
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Case studies Revisited

Feasibility study
 Demonstrator
 Comparative study
 Observational study
 Literature survey
 Formal model
 Simulation

Proof by construction; often by applying on a "CASE"
Demonstrated on a simple yet representative "CASE"
Score criteria check-list; often by applying on a "CASE"
Observing a series of "CASES"
"CASES" = selected papers
Often explained using a "CASE"
Test prognoses with real observations obtained via a "CASE"



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Spectrum of cases

Toy Example

Created for explanation
 (*foo/bar*, *Alice/Bob*)
 Simple model; illustrates differences

Exemplar

Accepted teaching vehicle
 ("textbook example")
 Simple but illustrates relevant issues

Case

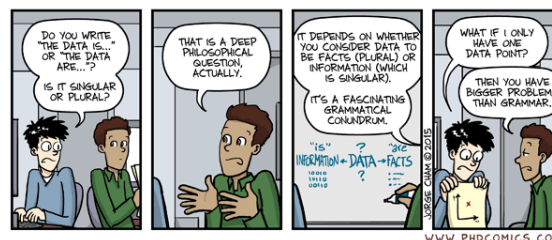
Real-life example
 Context is difficult to grasp

Community Case

Competition; approved by community, comparing, Kaggle

Benchmark

Approved by community (TPC-H, TPC-C, YCSB)
 Known context
 "Planted" issues



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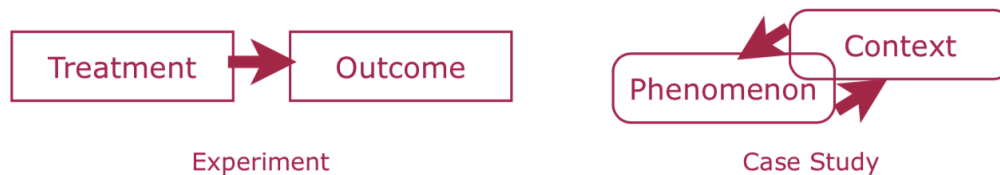


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Case study

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident

[Robert K. Yin. "Case Study Research: Design and Methods", p. 13]



⚠ Counter-Examples ⇒ Formal generalization is overvalued

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Steps to Perform Experiments

- Review relevant literature
- Specify the case study
 - Define objectives/hypotheses
 - Specify the population
 - Evaluate the testing feasibility
- Define research procedure (see next slide)

Research Procedure

Planning experiments/Case study

Treatment design
 Sampling/XP design/#replicates
 Measurements choice
 Units of observation
 Border effects / adjacent units
 Expected results
 Outline of analyses to do
 Measuring instruments

Experimenting/Studying

Install experiment
 Collect Data: each step!
 Complete analysis of data
 Finally, prepare a complete, correct, and readable report.

Need to restart? ⇒ Refine the “planning”

The 3 R's of experimentation

Repeat

Provide a measure of variation / error term;
 ⇒ Validity of conclusions.

Randomize

Treatments in a purely random manner;
 ⇒ Prevents bias.

Request Help

Not everyone is a statistician;
 ⇒ Do it when planning, not after.



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 - Proposing Experiments
 - My State of the Art & Experiments (bonus)

Some Practice on Use Case and XP

The goal is to plan some experiments on expected results

My work (Phase 0):

- Collected papers from related scientific domains;
- Removed experiments, title and authors (blinded);
- Put them [HERE](#).



Some Practice on Experimenting

Your work (Phase 1):

- Choose an article: 1 article = group of 3/4 persons;
- Read the article (without experiments);
- ⚠ DO NOT SEARCH THE ARTICLE ON THE WEB ⚠**;
- Propose a **title** and **experiments** (protocol and expected results);
- Write and explain *your* XP protocol in a document;
- Connect to Easychair and if necessary **create your account**:
<https://easychair.org/my/conference?conf=howtoxp24>
- Submit the article AND your "XP" on Easychair ⚠ **Add all your "co-authors" during submission**
- Deadline: Before 2pm.**



Articles



Easychair

Some Practice on Reviewing

Your work (Phase 2):

- Congratulations, you are in the Program Committee!**
- (I need your *Easychair* accounts)
- Do your biddings on Easychair (available until 7pm);
- Once you receive your assignment on Easychair, review it with proposed XP protocol (blinded), detailed review form:

Title	Help text	Kind	has text	text visible to authors	text required	has scores	score required	score visible to authors	Scores
Proposed title	The proposed title is appealing	text/score	✓	✓	✓	✓	✓	✓	none; simple (code of the article...); Not really appealing; Appealing; Attractive - I wish to read this article!
XP adequacy with the article	The detailed provided in the XP are related to the model / contributions provided by the article. How much adequate are the XP and helps to enhance the contributions?	text/score	✓	✓	✓	✓	✓	✓	(none); Irrelevant; Somehow adequate; Good for some points: datasets / competitors / measurements / predicted results; All points are good
Detailed protocol	Comment the quality of the experimental protocol. How much the experimental protocol is detailed?	text/score	✓	✓	✓	✓	✓	✓	None; Just a list of items; Few details; Argues for choices; Very detailed XP
Article difficulty	How much the complexity of this article helped the designing of the experiments?	text/score	✓	✓	✓	✓	✓	✓	Easy. Too much details were given in the article; Some details details guided; Few details. Most experiments are new; No details. great job!

Deadline: Tuesday 7pm.

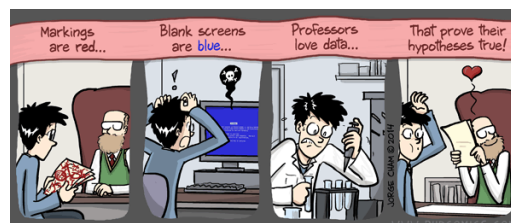
My work (Phase 3):

- Program Committee Chair: Process all the reviews
- I'll give you the feedback Wednesday evening!

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 - Proposing Experiments
 - My State of the Art & Experiments (bonus)

Back to Basics

- Take **your** state of the art (SoA) done so far;
- For each “*Case Studies*” assign an article from your SoA;
- Find argues to show how much experiments/demonstrations enhance the contribution;
- Present *one* of them in 5 minutes.
- All types of case studies will be illustrated by the class.



Some Practice on Use Case and XP

The goal is to classify articles

Classify your state of the art in terms of typologies (case studies)

Identify the "question learned" in each article